Annual Energy Outlook Retrospective Review: Evaluation of Reference Case Projections in Past Editions (1982-2009)

The Energy Information Administration (EIA) produces projections of energy supply and demand each year in the *Annual Energy Outlook* (*AEO*). The projections in the *AEO* are not statements of what will happen but of what might happen, given the assumptions and methodologies. The Reference case projection assumes trends that are consistent with historical and current market behavior, technological and demographic changes, and current laws and regulations. The potential impacts of pending or proposed legislation, regulations, and standards—or of sections of legislation that have been enacted but that require implementing regulations or appropriation of funds that are not provided or specified in the legislation itself—are not reflected in the projections. Thus, the *AEO* Reference case provides an impartial baseline that can be used to analyze potential new policies or legislative initiatives. The analysis in the *AEO* primarily focuses on a Reference case, lower and higher economic growth cases, and lower and higher oil price cases. However, approximately 30 alternative cases are generally included in the *AEO*. Readers are encouraged to review the full range of cases, which address many of the uncertainties inherent in long-term projections.

Each year since 1996, EIA's Office of Integrated Analysis and Forecasting has produced a comparison between realized energy outcomes and the Reference case projections included in previous editions of the *AEO*. Each year, the comparison adds the projections from the most recent *AEO* and updates the historical data to the most recently available. The comparison summarizes the variations of the *AEO* Reference case projections since 1982 to realized outcomes by calculating the average absolute percent differences for several of the major variables for *AEO1982* through *AEO2009* [1]. The average absolute percent difference is the simple mean of the absolute values of the percentage difference between the Reference case projection and the actual value. The historical data are typically taken from the *Annual Energy Review (AER)* [2]. The last column of Table 1 provides a summary of the most recent average absolute percent differences for 21 projection components. The detailed calculation of these differences is shown in Tables 3 through 23. These tables also provide the average absolute difference, which is the simple mean of the absolute value of the difference between the Reference case projection and the actual value. The calculated absolute average differences can change from one year's evaluation to the next due to prior year data revisions that often occur in the *AER*, the *Monthly Energy Review (MER)*, and occasionally in gross domestic product (GDP).

The National Energy Modeling System (NEMS) has been used to prepare the *Annual Energy Outlook* since *AEO1994*. The annual projection process begins with the development of assumptions for two key drivers--the world oil price and the macroeconomic growth environment—that is determined outside of the NEMS. While the integrated nature of NEMS may result in some feedback that slightly modifies the initial assumptions about world oil price and the macroeconomic growth environment, these feedbacks tend to be relatively small, so that the initial assumptions for world oil price and the macroeconomic growth environment largely determine the overall projection environment. To the extent that this general environment deviates from the initial assumptions, the NEMS projection results will also deviate.

[1] Note the *AEO2009* results are for the "Updated *AEO2009* Reference Case Service Report" reflects the impacts of the American Recovery and Reinvestment Act of 2009 that was passed after the publication of the formal hardcopy version. This version is only available on the EIA Website at: http://www.eia.doe.gov/oiaf/servicerpt/stimulus/pdf/sroiaf(2009)03.pdf. Note also the publication gap in the tables that follow, there was no publication of *AEO1988*.

[2] GDP and the GDP price deflators come from the Bureau of Economic Analysis, while coal prices to electric generating plants are from the *Monthly Energy Review* (*MER*).

Table 1. Comparison of Absolute Percent Difference Between *AEO* Reference Case Projections and Realized Outcomes

Average Absolute Percent or Percentage Point Difference						
Variable	***AEO82 to AEO2004***	***AEO82 to AEO2005***	***AEO82 to AEO2006***	***AEO82 to AEO2007***	***AEO82 to AEO2008***	***AEO82 to AEO2009***
Gross Domestic Product						
Real Gross Domestic Product (Growth Rate)*	1.2	1.2	1.1	1.1	1.0	1.0
Petroleum						
World Oil Prices	56.4	54.1	52.6	51.7	50.9	51.1
Total Petroleum Consumption	2.9	2.9	2.9	2.9	2.9	3.3
Crude Oil Production	4.6	4.7	4.9	5.1	5.5	5.8
Petroleum Net Imports	6.8	6.6	6.5	6.2	6.0	6.5
Natural Gas						
Natural Gas Wellhead Prices	67.5	64.9	63.1	61.1	59.1	57.6
Total Natural Gas Consumption	6.4	6.4	6.6	7.0	7.0	7.1
Natural Gas Production	4.6	5.0	5.7	6.0	6.2	6.2
Natural Gas Net Imports	15.2	14.9	14.7	14.6	14.3	15.6
Coal						
Coal Prices to Electric Generating Plants**	47.7	47.0	46.4	45.4	44.5	43.7
Total Coal Consumption	3.9	3.9	4.0	4.1	4.1	4.2
Coal Production	3.8	3.9	4.0	4.0	4.1	4.1
Electricity						
Average Electricity Prices	19.6	19.5	19.7	19.7	19.6	19.7
Total Electricity Sales	2.4	2.4	2.5	2.5	2.6	2.7
Total Energy, Carbon and Intensity						
Total Energy Consumption	2.2	2.2	2.2	2.4	2.5	2.8
Residential Energy Consumption	2.9	2.9	2.9	3.2	3.2	3.3
Commercial Energy Consumption	3.9	4.0	4.1	4.3	4.3	4.4
Industrial Energy Consumption	3.6	3.7	4.1	4.5	5.0	5.8
Transportation Energy Consumption	4.4	4.4	4.4	4.4	4.4	4.6
Total Carbon Dioxide Emissions	3.5	3.5	3.3	3.3	3.4	3.5
Energy Intensity	5.8	5.7	5.7	5.9	5.9	6.1

AEO - Annual Energy Outlook

Source: Statistics in Table 2 are a summary of the calculations in Tables 3 through 19. The data in Tables 3 through 19 are based on the 1982 through 2009 *Annual Energy Outlook* projections. Historical data are taken from the *Annual Energy Review 2008* , DOE/EIA-0384(2008) (Washington, DC, June 26, 2009) and the *Monthly Energy Review June 2009,* DOE/EIA-0035(2009/06) (Washington, DC, June 24, 2009).

Note: Projections of carbon dioxide emissions began in *AEO93* and were first evaluated in 2000 retrospective. Evaluation of energy intensity projections began in 2003. Revisions to historical data are reflected in this edition.

* The basis for GDP comparison is the projection differences in the growth rate of real GDP. Thus, the summary information for Table 3 is on a percentage point basis and is different from the other *AEO* concepts which are evaluated in levels.

** Coal prices to electric generating plants are from the *Monthly Energy Review* . Beginning in *AEO2003* , EIA electric generating projections incorporated combined heat and power (CHP) electricity generation in electricity generating plants. Prior to *AEO2003* , coal price projections reflected data collected, estimated, and reported to electric utilities and excluded CHP power generation.

Table 2 provides a summary of the percentage of years in which a particular data series is overestimated as well as the absolute percent projection differences. These concepts are summarized for the entire series of *AEO* Reference cases with additional columns isolating the NEMS-based *AEOs* (i.e., those beginning with *AEO1994*). The percentage of projected overestimates for each variable is calculated as the number of overestimates of that variable relative to the total number of projections made (i.e., for each *AEO* and each year projected). In an unbiased projection, we would expect the percentage of overestimates to be close to 50 percent when the sample size is large enough. Many of the sample sizes are relatively small, statistically speaking. The percentage of overestimates in the NEMS *AEO*s has improved (i.e., moved closer to 50 percent) relative to pre-NEMS *AEOs* for 12 of the 21 concepts shown in Tables 3 through 23. The average absolute percent differences are smaller in magnitude for the NEMS *AEO*s in all but 8 of the 21 comparisons.

Table 2. Summary of Differences between *AEO* Reference Cases and Realized Outcomes

	All AEOs		NEMS AEOs	
	Percent of Projections Over-Estimated	Average Absolute Percent Difference	Percent of Projections Over-Estimated	Average Absolute Percent Difference
Table 3. Gross Domestic Product, Actual vs. Projected	41%	1.0%	51%	1.0%
Table 4. World Oil Prices, Actual vs. Projected	55%	51.1%	26%	30.6%
Table 5. Total Petroleum Consumption, Actual vs. Projected	40%	3.3%	56%	3.0%
Table 6. Domestic Crude Oil Production, Actual vs. Projected	58%	5.8%	64%	6.5%
Table 7. Petroleum Net Imports, Actual vs. Projected	53%	6.5%	57%	4.7%
Table 8. Natural Gas Wellhead Prices, Actual vs. Projected	53%	57.6%	18%	32.7%
Table 9. Total Natural Gas Consumption, Actual vs. Projected	47%	7.1%	68%	7.0%
Table 10. Natural Gas Production, Actual vs. Projected	57%	6.2%	74%	7.0%
Table 11. Natural Gas Net Imports, Actual vs. Projected	41%	15.6%	60%	12.9%
Table 12. Coal Prices to Electric Generating Plants, Actual vs. Projected	78%	43.7%	57%	18.7%
Table 13. Total Coal Consumption, Actual vs. Projected	44%	4.2%	46%	4.9%
Table 14. Coal Production, Actual vs. Projected	64%	4.1%	52%	3.8%
Table 15. Average Electricity Prices, Actual vs. Projected	74%	19.7%	51%	11.6%
Table 16. Total Electricity Sales, Actual vs. Projected	38%	2.7%	35%	3.4%
Table 17. Total Energy Consumption, Actual vs. Projected	54%	2.8%	65%	3.3%
Table 18. Residential Consumption, Actual vs. Projected	60%	3.3%	61%	3.7%
Table 19. Commercial Consumption, Actual vs. Projected	35%	4.4%	34%	5.8%
Table 20. Industrial Consumption, Actual vs. Projected	72%	5.8%	87%	7.2%
Table 21. Transportation Consumption, Actual vs. Projected	37%	4.6%	64%	3.6%
Table 22. Total Carbon Dioxide Emissions, Actual vs. Projected	34%	3.5%	38%	3.5%
Table 23. Energy Intensity, Actual vs. Projected	71%	6.1%	93%	5.8%

As a general matter, energy consumption quantities tend to be less volatile and thus projected with greater accuracy than the relatively more volatile energy prices. Energy consumption has a certain amount of inertia inherent from the energy-consuming capital stock, lead times for capital purchase decisions, locked-in contract periods, and myopic decision making. Across all *AEOs* the average absolute percent difference between Reference case projections of energy consumption, energy production, and carbon dioxide emissions and realized outcomes have typically been under 6 percent, with the exception of natural gas consumption and production, which are just over 6 percent. As expected, the corresponding absolute percent differences are much greater for energy prices – in the 19 to 58 percent range. Both Table 2 and the individual tables which follow generally show reductions in the absolute average differences for energy prices and net energy imports over time. This general trend has been disrupted somewhat by the recent world oil price volatility of the last several years.

The underlying reasons for deviations between the *AEO* Reference case projections and realized history have tended to be the same from one evaluation to the next. The most significant are:

- Because of the long term emphasis of the *AEO*, the projected growth rates in real GDP used in the *AEO* projections are trend projections rather than cyclic. That is, business cycles, which are more appropriate for short term projections, are not reflected in the *AEO* projections, except to the extent they influence the early projection years. Because of this, over-projections of the growth rate in real GDP tend to line up with economic slowdowns or recessions, whereas under-projections tend to occur during expansionary phases of the economy. Because GDP is a good indicator of economic activity and drives energy consumption, the differences between projected energy consumption and actual consumption are often similar to the differences between the GDP projections and actual GDP (Table 3).
- Overestimation of world oil prices, particularly in publications prior to *AEO1997* (Table 4), resulted in underestimation of petroleum consumption. The crude oil price projections in the *AEOs* completed after 1997 tended to be underestimated, which led to overestimation of petroleum consumption. A prime example is the year 2008. All *AEO* projections for the year 2008, with the exception of *AEO2009* (the 2008 figures in *AEO2009* are part history and part projection), significantly underestimated the crude oil price (Table 4). These underestimated prices led to overestimates of petroleum consumption for all *AEOs* (other than *AEO2009*). (Table 5).
- The fuel with the largest difference between the projections and actual consumption has generally been natural gas. Regulatory reforms that increased the role of competitive markets were implemented in the mid-1980s making it difficult to project future developments based on historical data. The technological improvement expectations embedded in early *AEO*s proved conservative and advances that made petroleum and natural gas less costly to produce were missed. After natural gas curtailments that artificially constrained natural gas use were eased in the mid-1980s, natural gas became an increasingly attractive fuel source, particularly for electricity generation and industrial uses. Historically, natural gas price instability was strongly influenced by the changes in the world oil price. More recently, the *AEO* Reference case has overestimated natural gas consumption (Table 9) due to the significant underestimate of the natural gas wellhead price (Table 8).
- Coal prices to the electric power sector were almost always overestimated prior to *AEO1999* and underestimated thereafter (Table 12). In general, the *AEO* coal projections produced prior to the use of NEMS (*AEO1982* through *AEO1993*) did not explicitly model coal mining productivity. From 1985 through 2000, coal mining productivity improved by an average of 6.4 percent per year, reducing the cost of production, and resulting in lower coal prices. As a result, there was a tendency for pre-NEMS coal models to overestimate future coal prices. An additional factor, contributing to the overestimation of delivered coal prices in earlier *AEOs* was a sharp decline in coal transportation rates that began in the mid-1980s and continued through the 1990s. For the *AEOs* produced using NEMS (starting with *AEO1994*), coal mining labor productivity is explicitly modeled. However, the rather sudden switch from steadily increasing coal mining productivity during the 1980s and 1990s to a flat to declining productivity rate starting around 2000 and continuing though 2005 was not anticipated in most of the *AEO* Reference case projections generated using NEMS. As a result, there has been a recent tendency to underestimate coal prices especially post-2002.
- For projection years 2001 through 2008 earlier *AEOs* (*AEO1991* to *AEO1997*) tended to underestimate coal consumption while *AEOs* starting with *AEO1998* tended to overestimate coal consumption (Table 13). This is generally consistent with the pattern of total electricity sales (Table 16), which reflects the electric generation sector's dominant role in U.S. coal

consumption. Underestimation of natural gas prices to electricity supported the underestimation of coal consumption in the early *AEOs*.

- From *AEO1998* through *AEO2006*, U.S. coal production (Table 14) is overestimated in most years. For *AEO1991* through *AEO2002*, there was also a tendency to overestimate coal exports and underestimate coal imports, both of which contributed to an overestimation of U.S. coal production. From the *AEO2007* through *AEO2009*, Reference case projections of coal production have been underestimated. A confounding factor regarding projections of coal production is the mostly unpredictable pattern of annual coal stock withdrawals and builds. For example, a 38 million ton build-up of coal stockpiles in 2001 resulted in a higher production number, contributing to an underestimation of coal production for 2001 when the large stockpile was consumed in several *AEOs*. This result follows from the general *AEO* assumption that the supply and demand for all fuels will balance for all projection years other than their initial year that is calibrated to EIA's Short Term Energy Outlook projection. Historically, other notable changes in coal stockpiles include stock drawdowns of 44 million tons and 41 million tons in 1993 (a strike year) and 2000, respectively.
- Electricity prices were almost always overestimated in the *AEO* Reference case projections until the *AEOs* of the late 1990s, after which the pattern has reversed (Table 15). Electricity prices in the early *AEO*s assumed regulated, average cost pricing, where fuel costs make up roughly 40 to 50 percent of the total price. As discussed above, coal prices to electric generators were often overestimated in these *AEO*s, resulting in similar overestimation of electricity prices. In the more recent *AEO*s, electricity prices have been underestimated, again following the pattern in the coal and natural gas price projections and the partially deregulated generation market. In deregulated markets, natural gas tends to determine marginal electricity prices and follow the changes in the delivered natural gas prices. The recent underestimation of natural gas wellhead prices contributes to underestimates of more recent electricity prices.
- The level of future electricity sales was underestimated for nearly all projection years for the *AEO1991* through *AEO1997* Reference cases (Table 16). Since about 90 percent of the demand for coal results from electricity generation, the underestimation of electricity sales contributed further to the underestimation of coal consumption (in addition to coal prices being overestimated and natural gas prices being underestimated) in those years (Table 13). The underestimation of electricity sales was particularly large in *AEO1994* through *AEO1996*.
- Over the last two decades, there have been changes in laws, policies, and regulations that were not anticipated in the projections prior to their implementation. Even if some of these could have been predicted, the definition of the Reference case generally limits consideration to *current* laws, policies and regulations. Many of these actions have had significant impacts on energy supply, demand, and prices. For example, the Powerplant and Industrial Fuel Act (FUA) of 1978 restricted the use of natural gas in power plants and industrial boilers. After FUA was repealed in 1987, use of natural gas for electric generation and industrial processing increased sharply. Consequently, those *AEO*s completed prior to or immediately after repeal of the FUA, e.g., *AEO1986*, *AEO1987*, and *AEO1989*, underestimated natural gas consumption for year 2000 by considerably more than more recent *AEOs*.
- Technological improvements in both the production and use of energy have had significant impacts on the price, supply, and consumption of energy. Earlier *AEO*s typically assumed much slower technology development than actually occurred. This tendency was identified, in part, by this type of retrospective review. Beginning with the *AEO1994*, the projections were produced using the NEMS, which was designed to represent technology in a more detailed fashion. This has lead to an improvement in the representation of technological change in the *AEO*. As NEMS has evolved, additional studies on technological improvement have led to more optimistic assumptions in the more recent projections. Further, the adoption of modeling innovations, such

as learning-by-doing, have allowed the model to better reflect the impact on cost of experience with new technologies as they are adopted.

- External factors such as severe weather, economic cycles, and other supply and/or demand disruptions like hurricanes that strike the Gulf of Mexico rigs have also had an impact on the relationship between projections and realized outcomes, particularly in the short term. These types of events are not anticipated in a mid- to long-term projection like the *AEO*.

- Total energy consumption by sector has been added to the comparison tables beginning with the retrospective for *AEO2008* (Tables 18 to 21). Overall, the projection errors tend to be relatively small; however, some pattern of overestimation is evident. In the transportation sector, this tendency can generally be explained by the economic, fuel-specific, and external factors discussed above. A portion of the overestimation in the industrial sector results from underestimating the extent of structural shifts in the sector. The evolution of the U.S. economy away from energy intensive industries to less-energy intensive manufacturing and services has continued unabated for a few decades and has even accelerated in the many subcategories in the energy-intensive industries. Turning to weather, actual residential and commercial energy use have also been affected in the last 15 years by weather patterns that have been generally warmer than the 30-year average "normal" used in developing *AEO* projections.

- Since *AEO1994* (the NEMS-based *AEOs*) energy intensity has been the concept most often overestimated. Energy intensity for the retrospective comparisons is defined as the ratio of total energy consumption to *nominal* GDP. Nominal GDP is used for the comparisons because it has been revised less than real GDP and thus avoids additional comparison issues resulting from other changes to real GDP such as deflator revisions. As a ratio, the projection differences are dependent upon relative differences in energy consumption and nominal GDP. The post-*AEO1994* overestimates of energy intensity are the result of two "reinforcing" features of past projections. During the period through *AEO2000*, GDP tended to be underestimated, which imparts a tendency to overestimate energy intensity. Post-*AEO2000*, energy consumption has tended to be overestimated, once again imparting a tendency to overestimate intensity. The combination of these two occurrences has resulted in energy intensity being overestimated for most years for *AEO1994* forward.

See PDF for Tables 3 through 23